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2 September 1994

Mr. K.D. Sowell
Contracting Officer, Procurement Office
George C. Marshall Space Flight Center
Huntsville, Alabama 35812

Subject: Contract NAS8-38772
SEPAC Co-Investigator Report

Dear Mr. Sowell:

On behalf of Torsten Neubert, the project director, and to fulfill the requirements for Contract NAS8-38772 I am submitting the enclosed final technical report.

Copies of this letter and of the report are being sent to the codes listed in the Distribution List below.

Sincerely,

Bobbi Walunas

Bobbi Walunas
Grants & Contracts

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cc:
AP32-G,CN22D, AT01,CC01/Sheehan,JA12,COTR(Code JA92,Dinah Higgins),BF61,NASA STIF(2), Nishakawa
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FINAL REPORT ON CONTRACT NAS8-38772
SEPAC CO-INVESTIGATOR SUPPORT
FOR THE PERIOD SEPTEMBER 1, 1990 - JUNE 30, 1994.

This is a report of the work done on the above contract to the University of Michigan and under the direction of Dr. T. Neubert. Several tasks were undertaken as detailed below, including mission preparation and mission support, data reduction and analysis, and modelling of beam phenomena using a range of techniques.

1. MISSION PREPARATION

1.1. Ground Coordinated Experiments - FO13

Tasks included the final design of several Functional Objectives. One that we took particularely care of at the University of Michigan was the "Picket Fence" FO13 which aimed at creating ionization streaks at regular intervals (100s of meters) in the upper atmosphere along the Orbiter trajectory by pulsing the SEPAC Electron Beam Accelerator (EBA) at ELF frequencies, and to observe the life time, drift velocity of the enhanced ionization by ground based radars. For this FO a substantial effort was put into organizing ground observations coordinated with ATLAS-1 overflights. Groups at Los Alamos, Utah State University and Stanford University were involved in this efort. However, because of the early failure of the EBA, no observations could be performed.

1.2. Jicamarca Radar Observations

The SEPAC experiment carried a second "active" source, the plasma contactor (PC), injecting a dense Xe^+ cloud. The PC electrically neutralized the shuttle orbiter during beam injections [*Katz et. al.*, 1994]. One ground coordinated experiment was able to observe the xenon plasma cloud under rather interesting circumstances. In this experiment, the Jicamarca, Peru, radar located close to magnetic equator, was operated at times of shuttle orbiter crossings of the magnetic meridian of Jicamarca. Several observations of plasma density enhancements were observed that correlated with orbiter crossings. If, for instance, the orbiter was on a southward pass, crossing the meridian north of the radar, an enhancement above the radar was observed with a time delay and at an altitude that corresponded to the cloud drifting with the orbiter velocity component parallel to $\underline{B}$ and along that field line passing over the radar. The observations were presented at an AGU meeting [*Jost et al.*, 1992]. This dataset needs further reduction using Cornell software, and negotiations for an opportunity to do this at no cost has been ongoing. Dr. Jerry Jost, Mission Planning Coorporation, Houston, TX, is heading this efort.

1.3. Mission Simulations

Dr. Neubert attended all mission simulations and prepratory meetings held at MSFC, Alabama, and at SWRI, San Antonio, Texas.

2. THE MISSION

Dr. Neubert was part of the SEPAC ground support team at MSFC during the mission.

3. DATA ANALYSIS

3.1. Artificial Aurora Experiment

One of the experiments that were successfully executed was the Artificial Aurora experiment in which downward directed electron beam pulses were observed by the onboard AEPI camera supplied by Dr. Mende of Lockheed Palo Alto Research Laboratory. Observations were done at 427.8 nm of N_2^+. At the University of Michigan, with the help of one graduate student, a two-stream code modelling electron transport and neutral gas ionization within a beam was modified to include predictions of 427.8 nm emissions and was run with the SEPAC beam parameters. The results indicated an intensity of 1 kR was expected at the Orbiter, while the AEPI camera observed 5 kR. Furthermore, the horizontal extent of the emissions were larger than expected from the model. A more detailed analysis, which included taking advantage of the curvature of the earth's magnetic field, revealed that the observations contained three components (1) a tail - indicating the wake of the beam - which is not modeled by the two-stream code, (2) near-field emissions coming from within the first 10s of kilometers of the beam. These emission, being close to the camera, account for the large horizontal extent and high intensity. Finally, (3) far-field emissions, which are the classical collisional emissions modeled by the code. It was possible using the curvature of the magnetic field to identify these emissions in the AEPI observations. Model predictions agree with observations in both intensity and in altitude of emissions. This work was published in *Neubert et al.* [1994], where the bright near-field emissions were proposed to be stimulated by wave-particle intereactions and heating of the ambient electron plasma to energies above the 20 eV threshold energy for excitation of 427.8 nm.

3.2. Langmuir Probe Analysis

The previous flight of SEPAC on Spacelab-1 in 1985 revealed interesting harmonic emissions in the few hundred Hz-range in the current to the Langmuir probe during EBA operations. The amplitude of these emissions varied with beam pitch angle in a way similar to broad-band 1-10 kHz noise, with maximum emissions observed for parallel beam injection. In the ATLAS-1 flight of SEPAC, we looked for such emissions but saw none, except occationally. We attribute this to the fact that the PC was operating, creating a charge neutralized environment, therby damping plasma oscillations. The work was presented at an AGU meeting [*Taylor et al.*, 1992].

3.3. Analysis of CIV FO

Dr. Neubert has collaborated with a group at Princeton University lead by Dr. Choueiri on the modelling of PC neutral gas injections to study the Critical Ionization Velocity (CIV) phenomenon. Support has been given to the interpretation of Langmuir probe data and plasma wave observations as well as the conditions and parameters characterizing the gas injection. This work is still in progress and funded under other grants.

4. THEORETICAL AND MODELLING EFFORTS

Theoretical and modelling efforts have focussed on phenomena related to electron beam and plasma cloud injection from spacecraft. A large invited review paper on electron beam processes was published in Planetary and Space Science [*Neubert and Banks*, 1992]. In

addition to papers directly related to the SEPAC experiment, several "spin off" papers have also been published.

4.1 PIC Simulations

The grant has supported Dr. Ken Nishikawa and Professor Oscar Buneman at a modest level with the purpose of building a three-dimensional particle in cell (PIC) code to be used to study beam-plasma interactions and plasma cloud - plasma interactions. In 1991, the code was ready and was tested on a number of problems of increasing complexity, including plasma cloud drift across a magnetic field [*Neubert et al.*, 1992], solar wind magnetospher interactions [*Buneman et al.*, 1992], laser plasma interactions [APS talk; *Neubert et al.*, 1991], and problems in astrophysics [*Zhao et al.*, 1994a,b; *Nishikawa et al.*, 1993]. The beam problem was investigated in *Nishikawa et al.* [1994], where it was concluded that the often quoted Langmuir turbulence, and the bunching of electrons, is not enough to explain VLF radiation levels observed in beam experiments. The main piece of evidence was the discovery, that VLF whistler waves continue to be generated at increasing levels even after the Langmuir turbulence saturates. It was suggested that the transverse motion (gyration) of beam electrons is also involved in the generation of VLF waves.

The PIC code studies have lead to several papers and has been presented at a number of conferences world wide, thanks to the diligent efforts of Dr. Nishikawa. At this point we also wish to honor the spirit, wit, and support of Professor Buneman, who passed away January 24, 1993. We miss him.

4.2 Two-stream Code

The work with the two-stream code aimed at developing a tool to predict optical signatures of beam injections into the atmosphere as observed by the AEPI camera. Our efforts in this area have been described in section 3.1 above.

4.3 Bolzman Description

In collaboration with Dr. Khazanov of University of Michigan, beam injection from spacecraft was investigated using the kinetic Bolzman equation. The task here was to make a first attempt of including wave-particle interactions in the analytical description of beam-plasma interactions. Such model complements the two-stream description (no waves) and the PIC code (short time scales) very nicely. It was concluded that Langmuir turbulence could account for the enhanced flux-levels of backscattered electrons often observed in beam experiments. However, the model included elastic wave-particle interactions only, and it was also concluded that future models must include inelastic scattering [*Khazanov et al.*, 1993]. A paper describing the model in some detail as applied to the ionosphere-magnetosphere system was also published [*Khazanov et al.*, 1994].

5. PERSONEL

Directed by Dr. Neubert, the following persons have at some point received support on the grant:

Professor Oscar Buneman, Stanford University; consultant; PIC code development; solar wind - magnetosphere interactions.

Dr. K.-I. Nishikawa, University of Iowa; consultant; PIC code development; Solar wind - magnetosphere interactions, beam-plasma interactions, astrophysical plasmas.

Mr. James Choi, University of Michigan; Graduate Student; PIC code display software, PIC codes on SIMD parallel computers.

Mr. Srikant Ranganatan, University of Michigan; Graduate Student, Jicamarca preparations, Langmuir probe data analysis, general data analysis.

Mr. Ivan Chang, University of Michigan, Graduate Student, two-stream code modification, AEPI observations.

Mr. Yang Cha, University of Michigan, Graduate Student, PIC code simulations.

Dr. Jerry Jost, Mission Planning Coorporation, Houston, TX; Travel support to operate the Jicamarca radar.

6. PUBLICATIONS

6.1 Refereed Publications

Neubert, T., J. L. Burch, and S. B. Mende, The SEPAC artificial aurora, *Geophys. Res. Lett.*, **submitted**, 1994.

Burch, J.L., W. T. Roberts, W.W.L. Taylor, N. Kawashima, J.A. Marshall, S.L. Moses, T. Neubert, S. B. Mende, and E. Y. Choueiri, Space Experiments with particle accelerators: SEPAC, Adv. Space Res., 14, (9)263, 1994.

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Neubert, T., E. Ungstrup, and B. Gilchrist, AMPAS - a new active experiments mission, *Adv.Space Res.*, **in press**, 1994.

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Khazanov, G. V., T. Neubert, and G. D. Gefan, A unified theory of ionosphere-plasmasphere transport of superthermal electrons, *IEEE Trans. Plasma Sci., 22,* 187, 1994.

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Cai, D., L. R. O. Storey, T. Neubert, and P. M. Banks, Particle loadings of a plasma shear layer across a magnetic field, *J. Comp. Phys., 107*, 114, 1993.

Burch, J. L., S. B. Mende, N. Kawashima, W. T. Roberts, W. W. L. Taylor, T. Neubert, W. C. Gibson, J. A. Marshall, G. R. Swenson, Triggering of auroras with artificial electron beams, *Geophys. Res. Lett., 20*, 491, 1993.

Buneman, O., T. Neubert, and K. -I. Nishikawa, Solar wind-magnetosphere interaction as simulated by a 3D, EM particle codes, *IEEE Trans. Plasma Sci., 20*, 810, 1992.

Neubert, T., R. H. Miller, O. Buneman, and K.-I. Nishikawa, The dynamics of low-β plasma clouds as simulated by a 3-dimensional, electromagnetic particle code, *J. Geophys. Res., 97*, 12057, 1992.

Neubert, T., and P. M. Banks, Resent results from studies of electron beam phenomena in space plasmas, *Planet. Space Sci., 40*, 153, 1992.

6.2 Conference Proceedings

Neubert, T., I. C. Chang, J. L. Burch, J. A. Marshall, N. Kawashima, W. T. Roberts, and W. W. L. Taylor, The SEPAC artificial aurora, *International Symposium on Electron Beam Experiments in Space and its Applications*, Atami, Japan, March 25-27, 1993.

Nishikawa, K.-I., O. Buneman, and T. Neubert, Solar wind-magnetosphere interaction as simulated by a 3D, EM particle code, *Proceedings of the Fourth International Toki Conference on Plasma Physics and Controlled nuclear Fusion - Fusion and Astrophysical Plasmas - (Joint Varenna - Abastumani - Nagoia Workshop on Plasma Astrophysics), Toki, Japan,November 17-20, 1992, ESA SP-351, Feb. 1993.*

Nishikawa, K.-I., J.-I., Sakai, S. Koide, O. Buneman, and T. Neubert, Current loop coalecence studied by 3D EM particle code, *Fourth International Toki Conference on Plasma Physics and Controlled nuclear Fusion - Fusion and Astrophysical Plasmas - (Joint Varenna - Abastumani - Nagoia Workshop on Plasma Astrophysics)*, Toki, Japan, November 17-20, 1992, *ESA SP-351, Feb. 1993.*

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6.3 Reports:

Neubert, T., AMPAS - Active Magnetospheric Particle Acceleration Satellite, White Paper.

Banks, Neubert, et al., "Space Plasma Physics" - input to "Opportunities in Plasma Science and Technology" - NRC.

6.4 Seminars

Neubert, T., Electron beam experiments in space & the generation of artificial aurora, Niels Bohr Institute for Astronomy, Physics, and Geophysics, May, 1994.

Neubert, T., The SEPAC artificial aurora, Florida Institute of Technology, April, 1994.

Nishikawa, K.-I., O. Buneman, and T. Neubert, Solar wind-magnetosphere interaction as simulated by a 3D, EM particle code, *ESA confererence on Spatio-Temporal Analysis for resolving Plasm Turbulence*, January 31 - Febuary 5, 1993.

Taylor, W. W. L., T. Neubert et al., SEPAC on ATLAS-1: Waves induced by beam ionosphere interaction experiments, *URSI, General Assmbly*, January 1993.

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Nishikawa, K.-I., O. Buneman, and T. Neubert, Solar wind-magnetosphere interaction as simulated by a 3D, EM particle code, *Chapman Conference on Solar Wind Sources of Magnetospheric ULF Waves*, Sep 14 - 18, Williamsburg, VA, 1992.

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